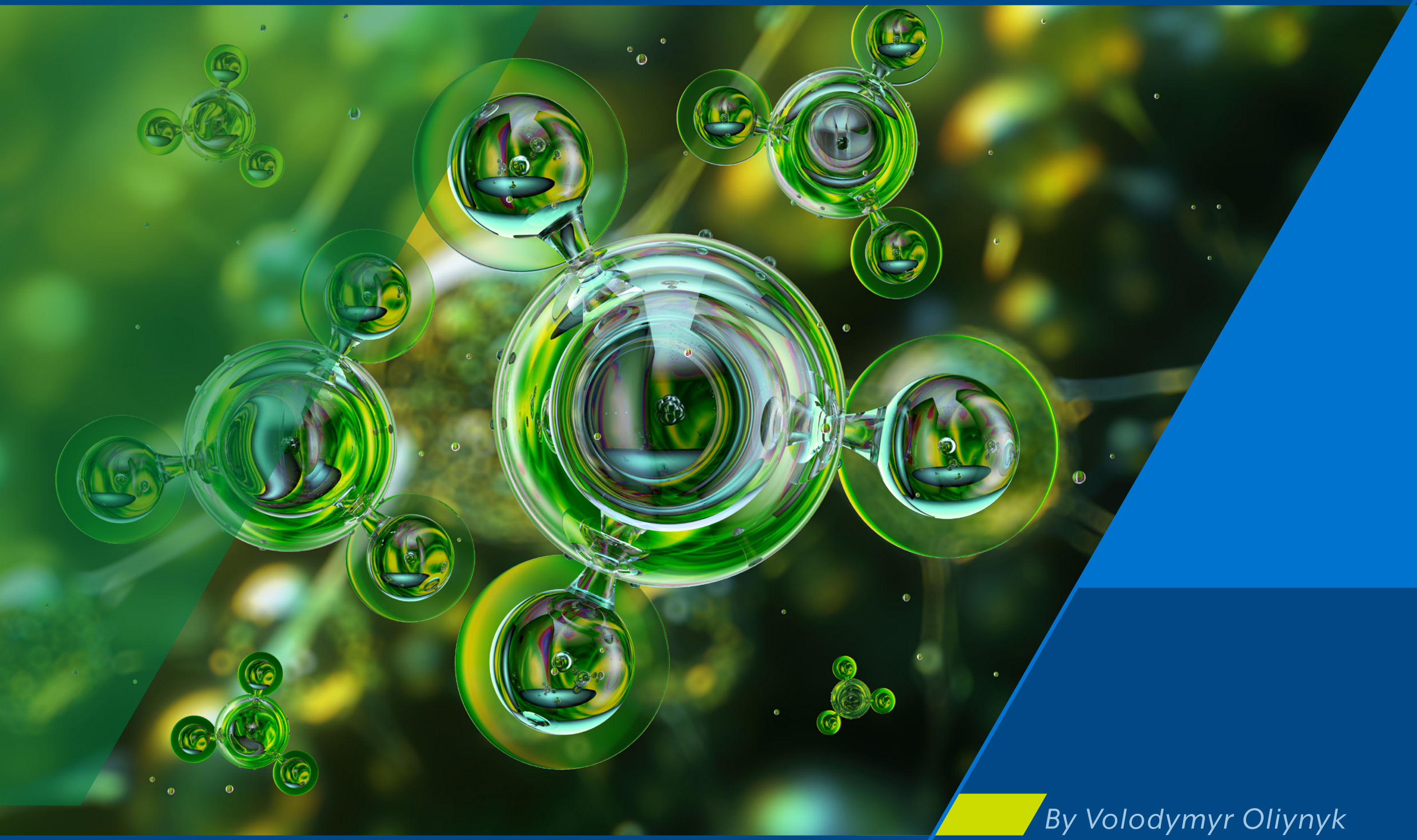
WHITEPAPER

AMMONIA REVAMP

KBR Response for Modern-Day Challenges



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Introduction

Ammonia Market and the Role of Revamping in Industry Development

The ammonia market is one of the most diversified industrial sectors, shaped by regional variations in population, resource availability, and technological advancements. However, one constant remains: ammonia production has been a cornerstone of modern agriculture, predominantly through the Haber-Bosch process developed in 1910/13. The availability of nitrogen-based fertilizers, made possible by ammonia production, has enabled the harvesting of high-yield crops on almost any type of soil. This has been crucial in feeding the growing global population and supporting agricultural economies worldwide.

Ammonia production technology has evolved dramatically, reducing energy consumption from extremely high levels in early plants to as low as 6.3 Gcal/MT in modern designs such as KBR Purifier technology. While many small-capacity units from the 1960s have been retired, numerous large plants built in the 1970s and 1980s remain operational. These facilities can continue operating for decades with proper maintenance but rising feedstock costs and outdated technology make them less competitive than modern plants.

With new construction costs exceeding $700 million to $1 billion, revamping existing plants offers a cost-effective solution. Upgrades such as advanced equipment, optimized process schemes, and modern control systems improve efficiency, reliability, and safety—ensuring long-term viability and supporting global food security.

Evolution of the Ammonia Industry

The rapid expansion of the ammonia industry started in the 1960s and 1970s, with more than 220 ammonia plants commissioned globally. These plants, with an average capacity ranging from 600 to 1,000 metric tons per day (MTPD), were primarily constructed in the countries with sufficient financial resources to invest in large-scale industrial infrastructure. Energy consumption at these units varied significantly, ranging from 12 Gcal/MT for the earliest plants to approximately 10.5 Gcal/MT for later designs. The market at this time was highly competitive, with up to 20 different licensors offering ammonia technologies. As a demand for ammonia-based products grew, these plants became integral to global supply chains.

In the 1980s and 1990s, the trend moved toward larger-scale plants with capacities between 1,500 and 2,000 MTPD. Around 120 new plants were commissioned during this period, benefiting from technological advancements that improved energy efficiency. Energy consumption at these units was reduced to between 9.5 Gcal/MT in the early 1980s and 8.6 Gcal/MT by the late 1990s. Alongside these improvements, the number of ammonia licensors began consolidating, with only the most advanced and sophisticated engineering providers remaining in the market—reducing from over 20 licensors in earlier decades to approximately eight by the 1990s. This period was characterized by rapid industrialization in Asia, especially in China and India, where ammonia production played a key role in supporting agricultural expansion and food security.

The third major phase of ammonia industry development occurred in the 2000s and 2010s, marked by the construction of even larger ammonia plants, with capacities reaching up to 3,300 MTPD. Approximately 90 new plants were commissioned during this time, with a strong presence in North Africa, Middle East, Asia, and the Pacific. These plants achieved further improvements in energy efficiency, consuming between 6.5 and 7.8 Gcal/MT. By this stage, the ammonia licensing market had stabilized, with three major licensors and KBR as the primary technology provider having the largest number of grassroots plants commissioned and most capacities built. However, despite improvements in efficiency, growing concerns about the environmental impact of ammonia production led to an increased emphasis on sustainability.

KBR is a global leader in ammonia revamps, having over 200 revamp projects executed at different engineering stages, starting from feasibility studies and extending to basic and detailed engineering, proprietary equipment supply, and commissioning support.

The Shift to Sustainability and the Need for Revamping

The 2020s ushered a new era of ammonia production with a clear focus on sustainability and affordability due to significant increase interest in ammonia as a potential carbon-free fuel. The industry is now moving toward low-carbon solutions, such as green ammonia, which is produced using renewable energy sources, and blue ammonia, which incorporates carbon capture and storage (CCS) to reduce emissions. Nevertheless, conventional ammonia production is expected to continue, particularly in geographies and nations where there is an urgent need to provide domestic food security. In these regions, urea as the main ammonia-based fertilizer remains critical for agricultural productivity.

At present, approximately 495 ammonia plants are in operation worldwide, with more than 350 of these built between the 1960s and 1990s. Many of these older plants still rely on outdated technologies, leading to lower energy efficiency and higher carbon emissions compared to modern facilities. In the current market with high energy prices, construction cost and growing demand for ammonia-based fertilizers it presents a significant opportunity for revamping; the process of upgrading and modernizing existing plants to enhance their performance.

KBR is a global leader in ammonia revamps, having over 200 revamp projects executed at different engineering stages, starting from feasibility studies and extending to basic and detailed engineering, proprietary equipment supply, and commissioning support. This extensive experience positions KBR as a key partner for plant operators looking to improve efficiency, increase capacity, and transition toward sustainable ammonia production.

Revamping offers multiple benefits, including:

- **Improved Energy Efficiency:** By incorporating advanced catalytic systems, improved heat integration, and modern process control systems, older plants can achieve substantial energy savings.
- **Capacity Increase:** Many revamp projects focus on debottlenecking existing facilities to increase ammonia production. This is substantially less expensive than construction of entirely new plants.
- **Co-Production of Green Ammonia:** Many legacy ammonia plants can be adapted to co-production of green ammonia via integration of hydrogen produced by electrolysis from green energy or completely revert to all green ammonia production.
- **Reduction of Carbon Footprint:** CO_2 emissions from older plants can be reduced through carbon capture technologies, facilitating the transition to blue ammonia production.
- **Reliability Increase:** Many legacy ammonia plants, despite years of operator-driven improvements, face reliability challenges with frequent failures of critical equipment, leading to extended downtime and production losses. Replacing these key components with modern designs has become a common and effective revamp strategy to restore reliability and ensure stable operations.

In ever changing geopolitical landscapes, revamping plays a different role—helping nations expand fertilizer production and strengthen food security.

The Strategic Importance of Revamping

Revamping has now emerged as one of the most cost-effective and efficient solutions for the ammonia industry to align with energy security and sustainability goals without requiring massive capital investment in new infrastructure. Instead of constructing entirely new plants, operators can modernize their existing facilities, improving energy performance, reduce operational costs, and extend plant life cycles. This trend is particularly evident in North America, where the ammonia industry in the past decade increasingly focused on carbon capture and utilization (CCU). Many existing ammonia plants are being converted into blue ammonia facilities, where CO_2 emissions are permanently sequestered or used for enhanced oil recovery (EOR). This approach allows traditional ammonia producers to meet stricter environmental regulations while maintaining economic viability.

In ever changing geopolitical landscapes, particularly in Africa, revamping plays a different role—helping nations expand fertilizer production and strengthen food security. Since many nations currently rely on imported ammonia or urea, investing in revamped domestic production facilities can significantly reduce dependence on foreign supply and stabilize local agricultural markets.

The representation of benefits from revamping existing units against new grassroots construction can be presented as specific investments per ton of product, as below:

Sample 1

Grassroots Ammonia Plant

- Capacity: 2,200 MTPD
- Cost: 550 MM USD
- Specific investment costs per ton of product: 550,000,000/(2,200 x 330) = 757 $/MT

Sample 2

Revamp from 1,560 to 2,200 MTPD

- Capacity: 2,200 MTPD
- Cost: 90 MM USD
- Specific investment costs per ton of product: 90,000,000/((2200-1560) x 330) = 426 $/MT

The investments per ton of the product in revamp case is nearly two times lower than for the grassroots plant—that is a great difference. Revamp projects present an opportunity for owner operators to self-fund large capacity expansions without need for outside investors (banks, private equity, etc.)

As the global leader in ammonia, KBR's expertise demonstrates the industry's trust in its ability to enhance operational efficiency, reduce emissions, and extend plant lifespans. In an era, where food security, clean energy production and environmental responsibility go hand in hand, revamping ammonia plants represents a vital step toward a more resilient global industry.

KBR's execution strategy towards complex revamp projects is based on the utilization of both "extensive" and "intensive" approaches to achieve the project's operation performance targets within the budget.

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KBR Revamp Approach

KBR Revamp Philosophy

The KBR approach for successful execution of a revamp project is based on the application of innovative and proven technical options together with deep understanding of the technologies and processes at the revamping plant.

The ammonia plant is a highly complex, heat-integrated industrial facility that combines various technologies and processes, utilizing hundreds of pieces of equipment and apparatus.

Two major postulates apply to the execution of an ammonia revamp project:

- Any change in operating conditions at any process unit of the revamped plant will inevitably impact the performance of other units within the plant.
- The individual effect of a specific revamp option is not fixed and may vary depending on the complete set of revamp options implemented.

This means that once a single revamp option is applied, material and heat balance of the plant must be recalculated, readjusted and rechecked, so there are no identical gains from the same revamp option under different revamp schemes.

There are two approaches that can be applied, when executing an ammonia revamp project:

- **Extensive:** Focuses on increasing capacity to achieve higher output. It typically involves adding more resources, equipment, or expanding infrastructure.
- **Intensive:** Relies on optimization, efficiency, and process improvements without significantly increasing physical infrastructure.

These approaches may be applied independently extensive primarily for capacity increase and intensive for energy efficiency enhancement.

KBR's execution strategy towards complex revamp projects is based on the utilization of both "extensive" and "intensive" approaches to achieve the project's operation performance targets within the budget.

Revamp Project Execution Stages

Any revamp project has these specific phases of development:

Feasibility study or process evaluation	Proprietary engineering design or project design documentation	Detail design	Equipment supply	Construction, commissioning and startup

While executing ammonia revamp projects, KBR always considers both non-proprietary technical solutions and proprietary solutions, whether developed by KBR or open art.

Feasibility Study

This stage is the most critical in an ammonia revamp project, as it identifies bottlenecks and determines strategies to overcome them while providing a preliminary economic analysis. At this point, the overall structure of the revamp project is defined. During subsequent engineering stages, this structure is refined into detailed construction packages and validated economically to support the Final Investment Decision (FID).

Base Case

Developing the base case simulation is a critical step in confirming existing bottlenecks and operational limits of the plant. This stage provides KBR with essential data points to accurately assess the plant's current condition, including realistic pressure profiles, heat transfer performance of heat exchangers under existing fouling conditions, compressor and turbine performance, and catalytic system activity. These validated parameters serve as the foundation for the revamp simulation, establishing the starting point for defining revamp conditions.

Revamp Case

KBR assesses utilization of different revamp options, involved modification of existing equipment and/or installation of new state-of-the-art equipment/processes/technologies, to achieve the revamp project targets. The provided options are applied to the static model based on results of the base case study.

Existing critical equipment that typically requires modifications, upgrades or replacement at the ammonia plant site include the primary reformer, waste heat boiler/s, carbon dioxide removal system, compressors/turbines internals and the ammonia converter.

While executing ammonia revamp projects, KBR always considers both non-proprietary technical solutions (not tied to any vendor or licensor) and proprietary solutions, whether developed by KBR or open art.

The non-proprietary solutions are typically related to utilisation of widely available engineering methods to achieve require performance by increasing size of the equipment, changing flowrate, streams distribution etc.

KBR has a number of proprietary technologies to offer for ammonia revamp projects, such as KRES™, Purifier technology and the add-on ammonia converter.

The proprietary solutions are typically owned by a specific vendor or licensor with protected IP. The examples of such solution are—BASF/UOP/GV CO_2 removal process, hydrogen recovery units (Linde, Air-Product, UOP etc.), machinery OMV's (MHI, GE etc).

KBR has a number of proprietary technologies to offer for ammonia revamp projects, such as:

- **Reforming exchanger KRES™ :** Increases ammonia production by augmenting capacity (up to 30%) of the front-end without any major modification to existing primary reformer.
- Modification of conventional plants to **Purifier technology:** Saves energy and provides large capacity increase (up to 40%).
- **KBR's add-on ammonia converter:** Allows achieving energy saving and capacity increase.
- Other proprietary items/technologies (waste heat boiler, **NH_3 wash, unitized chiller and etc.**)

Around the midpoint of the feasibility study, KBR presents to the client—at an interim meeting—one or more revamp cases (as agreed with the client). Each case includes a list of proposed modifications, material and heat balances, and a feed and fuel summary. Based on this review, the client selects the preferred case to be finalized for preparation of the final study report.

The final study report includes an analysis of plant operation with the proposed revamp options, Process Flow Diagrams (PFDs), material and heat balances, feed and fuel summary, a list of modified or new equipment, and a commercial section with the estimated Total Installed Cost (TIC) of the revamp project. Typically, a Class 4 TIC estimate with an accuracy of ±40% is provided to enable the client to decide on the next project development step.

This stage may be skipped if the client is fully satisfied with the technical evaluation of the proposed revamp options and the high-level cost estimate. In such cases, the project proceeds directly to the execution of Basic Engineering Design (BED) or Project Design Package (PDP) documentation.

Once the feasibility study results are approved by the client, the next stage of revamp project development is engineering, which can proceed in one of two ways:

- **Front-End Engineering Design (FEED):** Selected when the client requires more precise clarification of the expected TIC prior to the FID. After FID approval, the project moves to detailed design.
- **PDP/BED:** If the feasibility study results are sufficient for the client to make an FID, the next stage involves developing a basic proprietary engineering design. This package, prepared by KBR, provides the process design necessary for executing detailed engineering design.

Basic Engineering Design or Project Design Documentation

The basic Proprietary Engineering Design (BED) package provides all critical documents ensuring licensor's technology solutions – and the condition for process guarantees. In some cases, the package can be presented as a Project Design Package (PDP) that usually provides only process information and data to be used by a detail engineering contractor for further development or as an extended PED including detail design of critical transfer lines and piping related to proprietary equipment with stress calculations, preliminary 3-D model and other DD engineering parts that cannot be performed by the local contractor.

Detail Design (DD)

KBR has full engineering capability and can develop detailed design documentation as part of the revamp project. If the Client prefers to engage local engineering contractors, KBR provides engineering support or post-PED services. This scope typically includes:

- Reviewing detailed design documentation to ensure compliance with KBR's PED package.
- Participating in HAZOP reviews.
- Supervising construction activities related to the installation and handling of proprietary equipment supplied by KBR.

Equipment Supply

KBR manages and supports the complete process of equipment design, procurement, fabrication and inspection under a separate contract agreement with the client to ensure rigorous standards and quality are maintained.

Construction, Commissioning and Startup

Under a post-BED agreement, KBR provides essential services requires to support provided process guarantees and related to inspection/review/support of detail design documentation development, HAZOP participation, inspection/supervision during the installation of proprietary equipment (PEQ) and general support during commissioning and startup that can be provided upon request.

The revamp project always concludes with a performance guarantee test run (PGTR) for confirmation of KBR guarantees granted after the feasibility study phase.

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KBR Capacity Increase and Reliability Revamps

Application of 'Open-Art' Technologies

KBR's revamp expertise and experience are not limited only to proprietary technologies but takes full advantage of the decades of experience acquired by KBR Subject Matter Experts (SMEs) in the ammonia industry utilizing 'open-art' solutions and equipment schemes. Below is the list of revamp options utilizing non-proprietary technologies with brief description and their expected/possible benefits presented below:

Front-End of the Ammonia Plant

Enhanced heat recovery from the primary reformer with increasing it energy efficiency towards 90% and more, by utilization of low-grade heat from convection section of the reformer by:

1. **Installation of combustion air preheater (CAP)– energy saving 0.15–0.25 Gcal/MT**
    - Allows to increase energy efficiency of the SMR to 92-94%, reducing flue gases temperature before ID fan to 90°C–120°C.
    - Directly saves NG (fuel) to the burners of SMR.
    - The cost of changes to existing reformer is high, but energy gains are high as well and very attractive option for plants with high NG prices.
2. **Enhanced low-grade heat recovery by utilising it for pre-heating (hot water, LP steam), saturation of the process stream and etc.—energy saving 0.08 – 0.12 Gcal/MT**
    - Allows increased energy efficiency of the SMR to 87-90%, reducing flue gases temperature at the stack to 165°C-185°C.
    - Allows increased energy export (if required outside of the ammonia plant) and subsequently reduces overall energy consumption per tonne of product.
    - The cost of changes to existing reformer is moderate, with half or lower energy gain comparing with CAP (see above) and can be attractive if there are consumers of low-grade energy streams (process saturation, VAM machine, LPS/hot water export).
3. **A chiller can be added to the process air machine, which is cooled by chilled water made by utilization of low-grade heat at Li-Br Unit.**
    - Provided energy saving on the drive of the machine by utilization of low-grade heat into saving high grade heat to steam turbine of the machine.
    - This will help to overcome some limitation of the process-air compressor/turbine that is faced in many facilities during summer ambient conditions.
4. **Introduction of O_2 to the secondary reformer to increase capacity of the front-end:**
    - With primary reformer capacity becoming a limitation, this option allows to shift additional reformer duty to the secondary reformer.
    - It helps avoid invasive revamping of the primary reformer (radiant and combustion section, burners, ID and FD fans, etc.) but may require some adjustments in operation of secondary reformer.
    - It is possible to provide the required quality of O_2 for secondary reformer capacity enhancement by installation of new vacuum pressure swing absorption unit (VPSA) that is much more affordable vs utilization of air separation units (ASUs).

5. **Secondary reformer waste heat boiler**
   In case of substantial capacity increase it is possible that the waste heat boiler (101-C in KBR plants) downstream of secondary reformer may become a limitation providing non-reliable operation. KBR provides a full investigation of such cases following with recommendations to upgrade or substitute exiting WHB with a new and proven design.
6. **Optimization of the front-end pressure profile to minimize pressure drop from anchor point (outlet of SMR) to the suction of the synthesis gas compressor.**
   - At an ammonia plant of 2,000 MTPD capacity the saving of 1 bar at the suction of the 103-J provides about 300 kW energy saving by 103-JT.
   - Re-harping primary reformer radiant section with reformer tubes of larger ID.
   - Evaluating key piping bottlenecks and appropriate diameters.
   - Revalidation of the operation of heat exchangers at new operation capacity with recommendations for upgrades or replacement within existing shells/foundations to satisfy high capacity and lower pressure drop.
   - Possible parallel equipment installation to large catalytic converters with high pressure drops (HT/LT shift) that helps to provide high operation availability (catalyst reloading without plant shut-down) and energy saving on the 130-J/JT due to lower pressure drop.
   - Inclusion of stacked parallel flow HT/LT shift converters can improve dP while retaining existing plot plan and pipe routing.
   - Measures to decrease S:C ratio to decrease the total volumetric flow.
   - Advanced catalyst loading options providing lower pressure drop or increased conversion efficiency
7. **Performance optimization of CO_2 removal unit to provide capacity for additional load and to minimize energy consumption for regeneration steps. Potential energy saving 0.15-0.3 Gcal/MT.**
   - The reduction of energy consumption for solution regeneration can help to reduce S:C ratio to as low as 2.8 that substantially reduces fuel consumption in the primary reformer.
   - Upgrade of the packings in the columns to enhance mass-transfer process and possibly to reduce pressure drop in absorber.
   - Introduce two-stage solution regeneration process utilizing overhead vapour condensation heat from HP stripper to LP stripper operation.
   - Installation of a hydraulic turbine on the HP solution stream to drive the circulation pump.
   - Change of the low efficiency CO_2 removal solution technology (potash based) for a modern, highly efficient process (amine based).

In an ammonia plant of 2,000 MTPD capacity the saving of 1 bar at the suction of the 103-J provides about 300kW energy savings.

Back-End of the Ammonia plant

Transforming synthesis loop operation from “wet” to “dry” operation by removing moisture from make-up gas prior to mixing with circulation gas of the synthesis loop.

This option provides the possibility to reduce refrigeration duty, increase partial pressure of H_2 and N_2 that will enhance NH_3 conversion and provide protection to the ammonia catalyst against oxygenates that are catalyst poisons. The energy savings result from reduction of circulation rate on the synthesis gas compressor and subsequent reduction in power on the compressor turbine. There are two ways to provide such a transformation:

- **Ammonia wash unit:** Utilizing cold liquid ammonia to remove all moisture from the make-up gas is a very effective and economical way to convert synthesis loop into “dry” mode operation by removing water. However, it slightly increases the ammonia concentration at the inlet to the ammonia converter, which impacts the reaction equilibrium.

The KRES technology also provides some energy reduction in the fuel for the reformer between 0.03 to 0.05 Gcal/MT.

- **Molecular sieve driers:** This unit removes all oxygenates from the make-up gas, providing excellent catalyst protection. It is more effective than an ammonia wash for reducing circulation rates and offers the best energy savings. However, it comes with higher installation and maintenance costs and requires periodic replacement of molecular sieves.

Recovering hydrogen from the purge gases by one of the available processes—PSA or membrane separation is an effective way to save energy by reducing feed and fuel consumption by recycling recovered H_2 to the suction of the synthesis gas compressor.

The above options enhance the energy efficiency and can be used in combination with KBR's proprietary technologies to increase the capacity of the revamping plant.

KBR's Proprietary Technologies

KBR has developed unique technical solutions and equipment design, considered as proprietary. These technologies presented below have been successfully implemented in the ammonia industry and confirmed by long-term reliable operation.

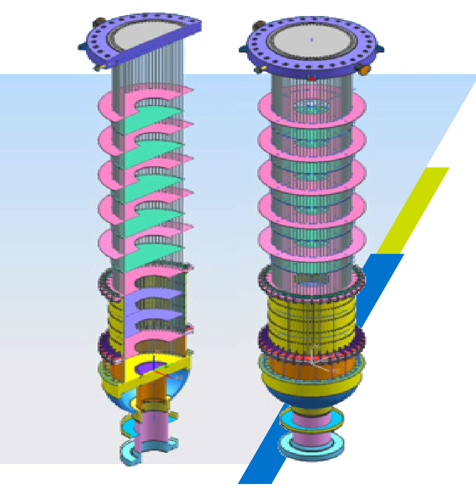
KRES™ – KBR Reforming Exchanger

This technology was developed by KBR in the 1990s and is based on the utilization of KBR-designed unique equipment—KRES, that allows reforming the hydrocarbon feed using high grade-heat of converted gas after the secondary reformer and without direct fuel firing. KBR offers this process for implementation to ammonia plants where such high-grade heat is available.

The application of the KRES can be in the following scenarios:

- **Grassroots plants:** Installed in parallel to the SMR + secondary reformer section allowing reduction in fuel burning in the SMR and subsequently on CO_2 emissions. This option is very attractive for "blue" ammonia or standalone ammonia production facilities where no extra steam is required.

- **Revamping plant:** Installed in parallel to the existing SMR + secondary reformer section, it allows production of up to 130% of SMR capacity. This option is good for capacity increase projects as it does not require significant modifications in the existing SMR and the majority of the work can be completed outside of the turnaround.



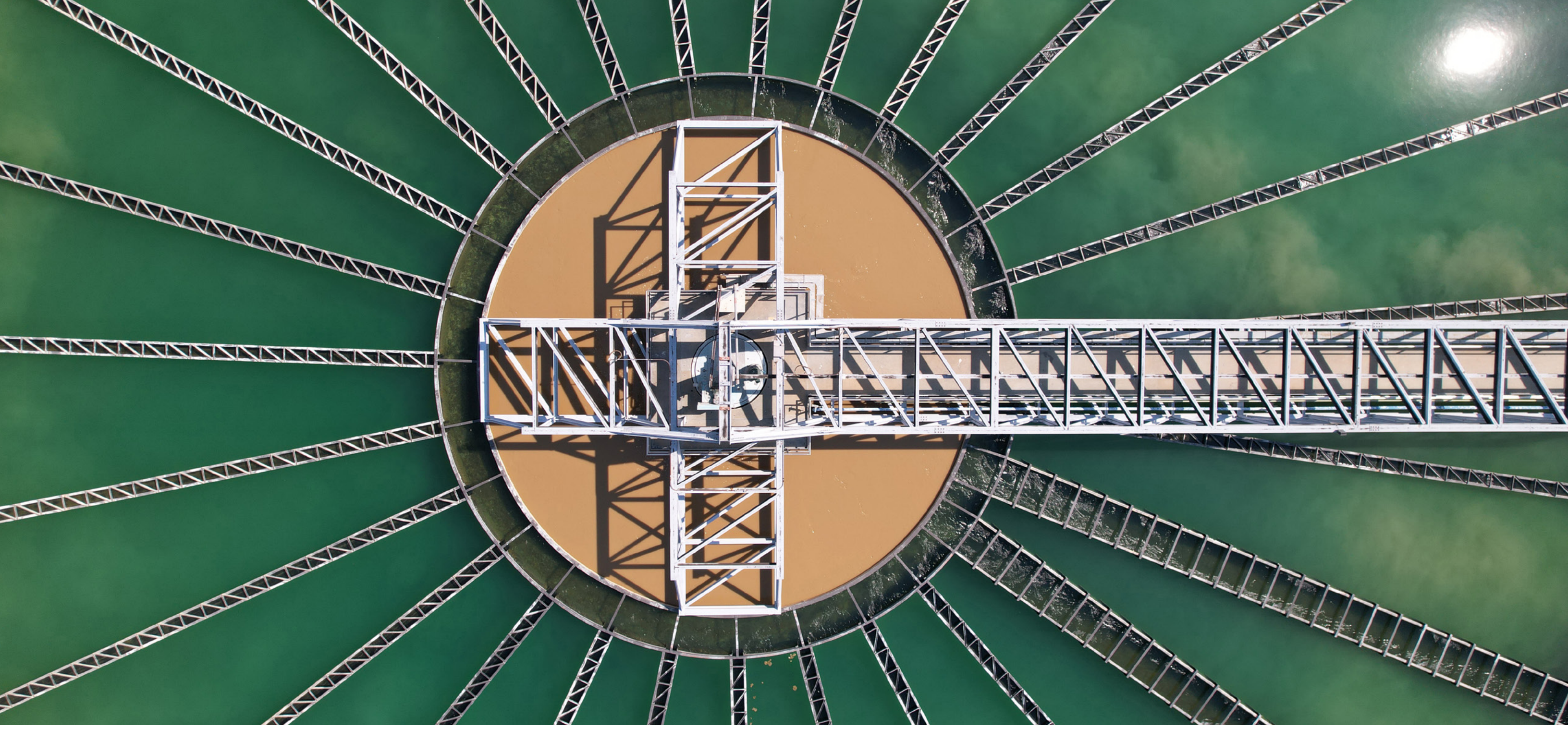
The KRES technology also provides some energy reduction in the fuel for the reformer between 0.03 to 0.05 Gcal/MT.

Waste Heat Boiler – 101-C

KBR's floating head boiler design has been successfully used since 1983 at all new ammonia plants, replacing the old-style bayonet boilers. The unique feature of this boiler is its water-tube cooled, floating head design with natural circulation and hot gas on the shell side. The new 101-C design also can be implemented at conventional technology plants by replacing old types of boilers 101-CA, 101-CB and 102-C with a single unit.

KBR implemented these boilers to replace outdated waste heat boilers during several revamps of ammonia plants. In such revamps the existing old-style bayonet boilers 101-C and 102-C are replaced with one boiler of a new design, which are installed on individual foundations during normal plant operation. It helps avoid complications with installation within the normal turnaround time. The new integrated 101-C design can also be installed within the existing footprint of the existing equipment in certain facilities.

There is no need to change the existing steam drum just reconnect existing risers to the new boiler.



Purifier®

This unique technology was initially developed and implemented in Braun's ammonia plants and later enhanced following the merger with Kellogg. Today, KBR's **Purifier** and **PurifierPlus** flowsheets represent the most energy-efficient ammonia processes available in the market. The lowest recorded net energy consumptionW**6.25 Gcal/MT**—was achieved at a Purifier plant operated by CFCL in India.

Together with opex benefits this technology provides the lowest capex at the construction, by reducing the sizes of the equipment in the reformer section and a synthesis loop that operates without inerts, avoiding the costs for HRU equipment. It is estimated that capex reduction is about 6-8% of the ammonia project total installed cost (TIC) .

The Purifier technology allows a shift in power consumption from the synthesis gas and refrigeration compressors (largest power consumers at ammonia plant) to the relatively lower front-end power consumers—process air compressor and NG compressor that substantially reduces fuel consumption at the plant.

The cold box 'purifies' the synthesis gases from inerts (CH_4, Ar, CO_2, etc.). Any excess methane from the front end (inert for synthesis loop) is removed in the Purifier and sent back to the front-end as a fuel. Consequently, the priority of having the lowest possible methane slip after the reforming section does not apply for the Purifier process. It allows a decrease in size of the SMR of up to 30% versus the conventional process of the same capacity and operation of the SMR + secondary reformer at much lower temperatures, drastically increasing reliability of the equipment.

The absence of inerts in the make-up gas to the synthesis loop improves the ammonia conversion and allows a reduction of operating pressure. The synthesis loop also operates at much lower circulation rate, providing major savings from power consumption on 103-J/JT and 105-J/JT. The quantity of the inerts (mostly Ar) is so low that the plant does not have a constant purge gas but rather periodical and the scheme does not require a hydrogen recovery unit (HRU).

The Purifier unit itself consists of three major items:

- Expander
- Feed/Effluent exchanger
- Rectifier column

The warm synthesis gas is cooled by cold purifier gas to around minus -175°C and then washed by liquid nitrogen to remove inerts. The inerts return to the fuel system and a clean mixture of N_2 and H_2 is sent to the synthesis loop.

Ammonia Converter – 105-D

Since the introduction of the first ammonia plant, KBR has consistently utilized proprietary designs for ammonia converters. Over the years, KBR has developed multiple multi-bed configurations, including both vertical and horizontal designs, each offering distinct benefits based on factors such as technology selection, plant capacity, plot plan constraints, and client preferences for maintenance.

In general, KBR recommends vertical converters for plants with capacities below 2,000 MTPD, while horizontal converters are suitable for capacities up to 6,000 MTPD using a single horizontal unit.

For revamp projects, KBR may propose the addition of a single-bed, cold-wall design add-on converter. Installed in series with the main converter, this proven design functions as an additional catalyst bed, enabling ammonia conversion rates of 21–24%. This approach increases synthesis loop capacity without requiring major investments in expanding existing equipment.

Unitized Chiller – 120-C

This unique KBR equipment integrates the functions of several components typically used in conventional ammonia plant refrigeration systems. It features multiple compartments, where liquid ammonia evaporates at different pressures and temperatures, combined with a central coaxial tube bundle.

Such a design allows drastic reduction in pressure drop for the recycled gas and saves energy during the recycle stage of synthesis gas compressor.

This is a standard piece of equipment for all KBR design ammonia plants since 90s but can be considered as a possible revamp option for substantial energy reduction.

3

KBR Sustainability and Carbon Reduction Revamps

With increasing emphasis on sustainable operations, ensuring food security has created a complex affordability challenge in a commoditized market. Therefore, partnering with a technology provider that offers maximum flexibility is essential for producers to achieve the right balance between TIC and return on investment (ROI).

KBR's ammonia revamp business provides the following advanced solutions in addition to those previously mentioned:

- Substitution of fossil feedstock with renewable sources
- Conversion of fossil-fuel-based ammonia plants into "green" operations
- Implementation of post-combustion capture technologies for carbon sequestration, utilization, or urea upgrades

Feedstock Substitution

- KBR has executed numerous feasibility studies for various clients to evaluate the potential for gradual substitution of fossil feedstocks and fuels with by-products from units powered by renewable energy sources. Typically, this involves using renewable electricity with electrolyzer technologies to produce "green" hydrogen, which is then introduced into the ammonia plant.

- The preferred point of hydrogen integration is downstream of the methanation unit. However, strict quality requirements are applied—particularly regarding oxygen contaminants—to ensure the hydrogen does not poison the ammonia converter catalyst.
- Different regions adopt varying strategies for ammonia plant revamps with Europe and USA focused on carbon reduction (C+ reduction) initiatives, and Asian countries for partial transition toward "green" ammonia production, integrating renewable energy sources. As a result, it was identified that there are three major reduction phases for conventional ammonia plants, as following:

Green Hydrogen: Low-Level Integration

KBR has determined that most ammonia plants can utilize imported hydrogen without major impacts on existing equipment operation.

- Conventional Plants: Up to 5-6% of feedstock can be substituted with green hydrogen without requiring equipment changes, modifications, or additions.
- Purifier Process Plants: Up to 12% substitution is possible under the same conditions.

This flexibility is enabled by adjusting the primary reformer operation, specifically by reducing the outlet temperature.

Green Hydrogen: Mid-Level Integration

KBR has identified that the next threshold for green hydrogen utilization is approximately **17-19%** substitution of natural gas (NG), achievable through a revamp of ISBL equipment without installing a new air separation unit (ASU) for additional nitrogen supply.

To accommodate this level of substitution, the front-end of the ammonia plant must be upgraded to withstand increased temperatures in the secondary reformer. Required modifications include adjustments in the convection section of the reformer and replacement of certain heat exchangers. However, no major changes are needed for compressors or the synthesis loop.

The primary limitation for further hydrogen integration is the rising temperature in the secondary reformer, which risks exceeding the design temperature of waste heat boiler (WHB 101-C).

KBR has determined that most ammonia plants can utilize imported hydrogen without major impacts on existing equipment operation.

Final Limit for Partial Green Hydrogen Substitution

KBR has identified that the ultimate threshold for hydrogen substitution is approximately **30%,** achievable without major implications for existing ammonia plant equipment.

To exceed previous limits for 103-D and 101-C, the process air compressor flow must be reduced, and additional nitrogen must be imported from OSBL. This nitrogen must meet strict quality requirements, with oxygen content limited to below 10 ppmv to prevent catalyst poisoning.

At this substitution level, the availability of high-pressure steam required to drive the synthesis gas compressor becomes a critical constraint.

Green Hydrogen Full Substitution

A conventional ammonia plant can be converted into a 100% green operation by completely substituting natural gas with green hydrogen and nitrogen supplied from OSBL.

This major modification would leave only the synthesis loop equipment in operation, with the main machines—such as the synthesis gas and refrigeration compressors—converted to motor-driven systems. The remaining ISBL equipment would no longer be required.

However, if hydrogen is supplied from renewable energy sources, critical updates to the control system and storage facilities are necessary to ensure a stable and continuous hydrogen flow for reliable ammonia loop operation.

Post-Combustion Capture

KBR offers a post-combustion capture process that removes high-purity CO_2 from flue gases through physical absorption. The captured CO_2 can then be compressed, liquefied, and transported via pipeline for sequestration.

Several licensors provide CO_2 removal technologies for industrial gases, including flue gases. The key challenges in flue gas treatment are:

- Low-pressure absorption, which requires larger absorbers and can become a limiting factor for high flue gas flow rates.
- Solution degradation, as flue gases tend to react with the absorbent, reducing reliability.

KBR is not a licensor of CO_2 absorption technology but collaborates closely with leading providers such as BASF, GVT, and MHI, offering their proven technologies through KBR. These licensors have experience in implementing CO_2 removal processes with acceptable resistance to solution degradation.

KBR remains flexible to client preferences in selecting the CO_2 removal technology and is ready to deliver a complete engineering solution for the process unit. Implementing post-combustion capture in a revamp project can achieve 98-99% overall carbon capture.

Summary

KBR's leadership in ammonia technology is built on decades of experience designing and executing grassroots ammonia plants—expertise that translates directly into unmatched capability in plant revamp projects. This deep understanding of ammonia production fundamentals allows KBR to diagnose operational challenges, engineer robust solutions, and deliver reliable performance improvements.

KBR takes a flexible, client-focused approach to every revamp, beginning with a detailed assessment of plant objectives and real operating conditions. From feasibility and process studies through proprietary and detailed engineering, KBR ensures that every solution is technically sound and commercially optimized.

Once engaged, KBR supports the full project lifecycle: engineering, equipment and catalyst supply, construction and commissioning advisory services, and performance-guarantee test runs. This end-to-end involvement ensures seamless execution and predictable results.

With proven experience in capacity expansion, energy efficiency improvements, and sustainability-driven upgrades, KBR offers comprehensive, high-value revamp solutions that help operators maximize the performance and longevity of their ammonia assets.

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